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Research Report

VISUAL CONTROL OF HABITUATION TO COMPLEX VESTIBULAR STIMULATION IN MAN*

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SUMMARY PAGE

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THE PROBLEM

Twenty men completed an experiment in the Pensacola Slow Rotation Room while it rotated for several hours at a rate of 45 deg/sec. Subjects were immobile (relative to the room) except for habituation series which consisted of head movements restricted to one plane and to a particular quadrant of that plane. Visual problems were presented with each head movement to one group of subjects; another group made all head movements of the habituation series in darkness.

FINDINGS

Tests conducted in darkness before and after the habituation series revealed pronounced reductions in nystagmus and subjective effects in the practiced quadrant only in the "visual-task" group. The other group showed no reduction of nystagmus in either the practiced or unpracticed quadrant. This experiment considered together with another experiment just completed indicates that vision can be an important factor in habituation of human subjects to vestibular stimulation.

Author

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INTRODUCTION

Reduction of nystagmus due to repetitive presentation of unnatural vestibular stimuli has been the subject of a number of recent experiments (7,8,9,21,24,29). During any one reaction, vestibular nystagmus may be facilitated or suppressed by visual stimulation depending upon the presence or absence of relative motion between the subject and his visual surroundings (28). The specific question under investigation is whether or not visual suppression of vestibular nystagmus during each of a series of vestibular stimuli (habituation series) will influence nystagmus habituation* as indicated by vestibular tests applied in darkness before and after the habituation series.#

The operation of subtle factors is suggested by older studies which have indicated 1) that nystagmus habituation is prevented by vision in pigeons with heads free (27); 2) that nystagmus habituation is specific to the response direction inhibited by vision in pigeons with heads fixed (27); and 3) that nystagmus habituation in pigeons is facilitated by vision (1). Many studies have shown that nystagmus habituation may occur in the absence of visual stimuli (7,8,27,29), but the extent to which this is attributable to reduced arousal is problematical (7,20). Wendt (31,32) has suggested that nystagmus reduction with repetitive stimulation in the dark is attributable to increasing dominance of reverie states; but when visual reinforcement of still fixation is provided during the habituation series, nystagmus decline may be attributable to competition between visual and vestibular systems with vision gaining dominance. Several studies (4,10,14) of subjective effects offer general support to Wendt's position; but recent studies have indicated that vision does not facilitate nystagmus habituation (8,29) in any respect.

Typically, experiments relevant to this issue have involved a routine introduction of light during or after passive angular acceleration of men (4,14,15) or of restrained animals (8,27,29). The present experiment differs from most of the previous studies in that it involves a) voluntary initiation of complex vestibular stimulation, and b) voluntary (active) visual suppression of nystagmus in man.

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*For convenience, the term <u>habituation</u> will be used to refer to a reduction in response detected by tests given before and after a series of vestibular stimuli; no other implication is intended.

#Tests for habituation under conditions of visual stimulation which differ from those of the habituation series may constitute an important variable in detecting series decrements (cf. Mowrer, 1934, p. 43; compare Paragraphs 8 and 9).

The complex sensory stimulation in the present experiment is noteworthy. When the body rotates with constant velocity, $\underline{\omega}$, if the head is tilted to rotate about an axis (head-tilt axis) orthogonal to $\underline{\omega}$-axis (see Figure 1), each endolymph ring undergoes a change in angular momentum. Those endolymph rings in planes nearly orthogonal to both the $\underline{\omega}$-plane and the head-tilt plane undergo a greater change in angular momentum per unit time than those rings which momentarily are nearly coplanar with the $\underline{\omega}$-plane. The stimulus may be conceptualized as an inertial torque about a third axis, orthogonal to $\underline{\omega}$-axis and to the head-tilt axis.* Hence, during $\underline{\omega}$, when the head, initially upright, is tilted laterally in the frontal plane, an inertial torque would commence immediately to stimulate the vertical canals, but as the skull's sagittal plane departs this position, stimulation of the "vertical canals" would diminish while that of the "horizontal canals" would increase. Termination of the head tilt terminates this inertial torque but does not reverse its direction. Thus the cupula is left in a deflected position to return to rest eventually by its inherent elasticity.

During this time the otolith system would be principally influenced by change in orientation relative to gravity. Hence the pattern of influx from the canals would be antisynergic to the intellectual, otolith, and proprioceptor information derived from the voluntary head movement, and the canalicular pattern itself could be bizarre with some movements.

Because the unusual aspects of the stimulus to the canals during concomitant $\underline{\omega}$-axis and head-axis rotation about orthogonal axes can also be conceptualized as deriving from different magnitude Coriolis accelerations around the endolymph rings, the vestibular reaction in this situation has been named the Coriolis phenomenon (26, 30), and the stimulus situation has been called the Coriolis vestibular stimulus (3, 18).

Graybiel, et al., (11) have introduced a fruitful line of experimentation wherein subjects are required to move the head or the whole body while enclosed in a slowly rotating room (SRR). Considerable difficulty in maneuvering as well as various neurovegetative symptoms are present initially, but after prolonged exposure, nystagmus, illusory phenomena, and the neurovegetative symptoms decline markedly. Results were obtained which suggested that vision enhanced the decline of the undesirable subjective effects (10).

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*Angular accelerations about the head-tilt axis would be effective during the movement, but at termination of head-tilts of 90 degrees or less their net effect would be negligible due to the temporal proximity and opposite signs of the acceleration and deceleration.

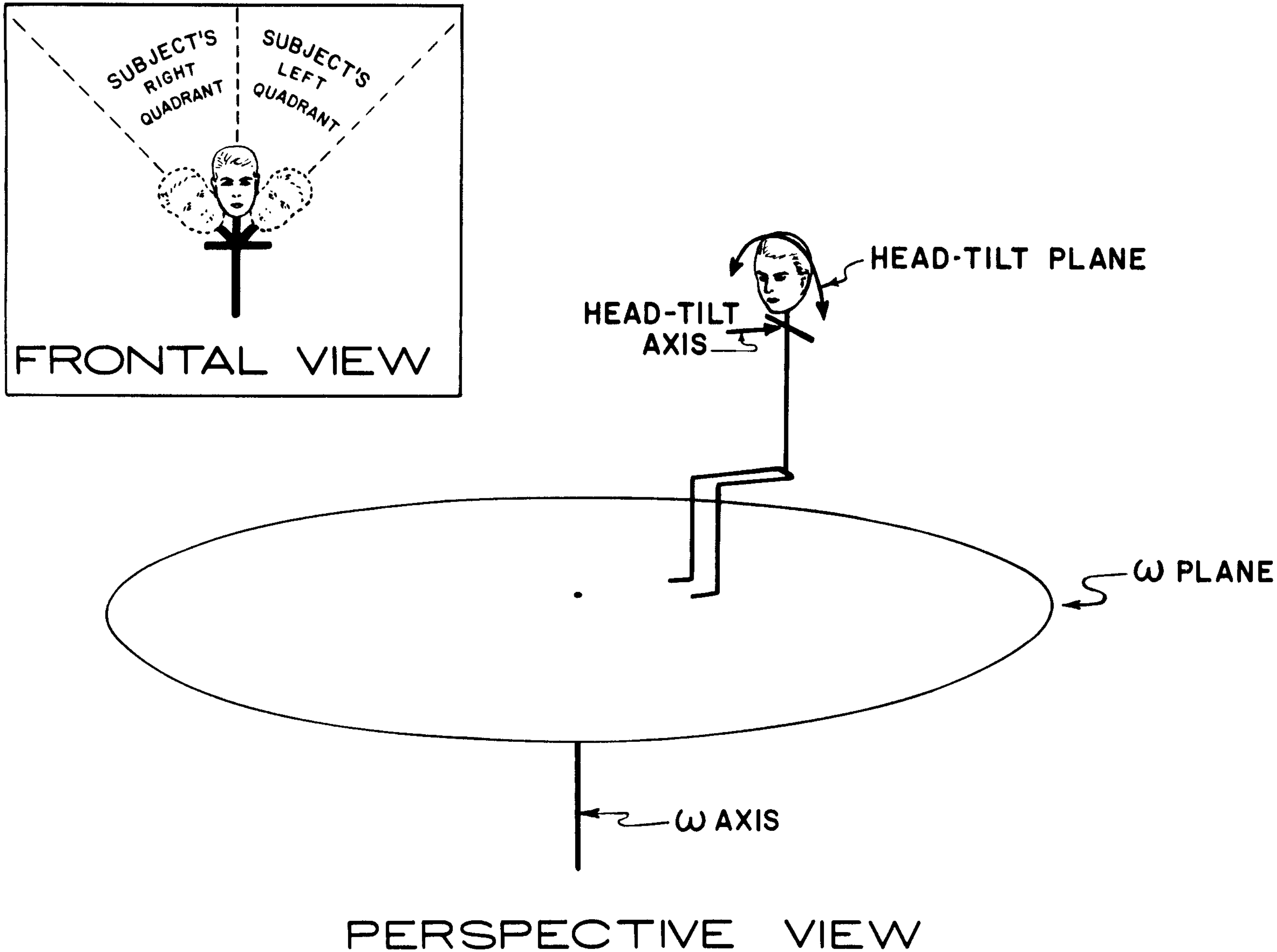

Figure 1

Illustration of Planes and Angular Displacements Used to Elicit the Coriolis Vestibular Reactions

In a recent experiment (19) in the SRR, men rotated for several hours and made a series of restricted head movements in the frontal plane (see Figure 1) and in only one quadrant of this plane with the room illuminated. Before and after the habituation series, head movements were made in both left and right quadrants. Results indicated that nystagmus and vestibular sensations declined in most subjects in the practiced quadrant. In the unpracticed quadrant, nystagmus response declines were slight. During the habituation series, vision was permitted, but visual performance was not required.

The nature of the experiment, restricted repetitive head movement without apparent purpose, was conducive to drowsiness, and a few subjects occasionally closed their eyes, apparently inadvertently, during the habituation series, contrary to instructions. Some of these subjects failed to show a decline in nystagmus or subjective effects, and it was suspected that lowered attentiveness to the visual surroundings contributed to the deviant results.

The present experiment differs from previous work (19) in one important respect. During habituation as the head was moved, tests of mechanical comprehension and spatial relations were presented to one group of subjects by a slide projector; multiple-choice answers were required. Thus with each head movement, executed in response to the click of the projector, a visual stimulus was presented which required voluntary control of eye movements when vestibular nystagmus would otherwise be expected to occur. Another group of subjects received the same habituation series in regard to vestibular stimuli but made all head movements in darkness. The purpose of the experiment was to test the hypothesis that a visual task which enforces voluntary control of eye movements during vestibular stimulation will influence habituation evidenced by nystagmus and subjective effects.

PROCEDURE

Experiments were carried out in the Pensacola Slow Rotation Room (SRR), a multi-sided room 15 feet in diameter and 7 feet high. This room, described in detail elsewhere (5), is capable of prolonged constant angular velocity with little, if any, perceptible noise or vibration associated with the rotation. The room's interior may be fully illuminated, or it may be darkened to exclude visual fixation stimuli. Each of four chairs, facing the center of rotation and located 4 feet from center, was equipped with a biting board arrangement to restrict head tilts to the frontal plane, as shown in Figure 1. Potentiometers attached to the pivotal shafts were used to record head movements.

Eye movements were recorded by the corneo-retinal potential method. Pairs of electrodes placed above and below one eye and at the outer canthus of each eye were used to record the vertical and horizontal components of nystagmus, respectively.

The potentiometer signals and the preamplified corneo-retinal potentials were fed through slip rings to a Sanborn recorder which was in an external room.

Estimates of subjective effects were also obtained. Subjects observed a small target light during head movements and estimated the intensity of subjective effects by assigning numbers on a 0 - 10 scale, for reactions ranging from absence of sensation to very intense sensation.

Subjects were 22 officers and cadets in the naval aviation program, with apparently normal vestibular function and an age range of 20 to 24 years. Of these men, 20 completed the experiment in two groups of 10 subjects each. Both groups received identical tests before and after the habituation series. During the habituation series, which lasted for several hours, the room rotated at 7.5 RPM (45 deg/sec). Tests consisted of lateral head tilt toward the left shoulder and a return movement to upright position, followed by a lateral tilt to the right shoulder and return movement to upright position. Total angular displacement in each head movement was 45 degrees, and this was accomplished in about two seconds. Each head position was maintained until the nystagmus reaction was completed, plus an additional thirty seconds.

The only difference in the treatment of the two groups occurred in the habituation series. In this series, Group A, the visual-task group, was required to solve problems of mechanical comprehension and spatial relations presented on a 10 inch by 10 inch luminous screen 3 feet from the subject. Heights of letters in the reading material spanned 9 minutes of visual angle. Subjects were told that their abilities under adverse circumstances were being tested, and a competitive attitude prevailed. Slides of interesting scenes were randomly introduced for diversion and to maintain interest. Fingertip pushbuttons were provided with which subjects indicated multiple choice answers which were automatically scored.

Group B (dark unoccupied group) made all head movements during the habituation series with eyes closed and in a semi-darkened portion of the room. Head movements of this group were also signaled by the click of the slide projector, although the projector and screen were not visible to these subjects. Two subjects in this group were unable to complete the experiment due to "rotation sickness"; thus, of the 12 subjects who commenced the experiment under Group B conditions, a total of 10 Group B subjects completed the experiment.

The habituation series for both groups consisted of 100 head-movement cycles, i.e., 100 tilt and 100 return movements in the right quadrant, while the SRR rotated counterclockwise at an angular velocity of 7.5 RPM. Each head position was maintained for twenty seconds during habituation series except for ten-minute rest periods which were given after each series of 20 tilt-return cycles. During these periods, subjects

rested by means of a comfortable head support. An "on-board" observer insured that head movements were restricted to those specifically required.

During all tests of nystagmus at the beginning and end of the day's run, i.e., before and after the habituation series, nystagmus was recorded in darkness while the subject, with eyes open (cf. Guedry and Montague, 1961, p. 491), did mental arithmetic to avoid loss of nystagmus due to arousal factors (cf. Collins, 1962). Subjects were also tested at these times for the Coriolis oculogyral illusion (12). Tests involving the same head movements were conducted also with the room stationary (static tests) before and after the entire procedure just described to detect compensatory reactions which might have developed (cf. Guedry and Graybiel, 1962).

In addition, when the SRR was started and stopped in tests before and after the habituation series, nystagmus was recorded from some of the subjects to determine whether or not there was any transfer of habituation from the series of head movements to the nystagmus occasioned by passive angular acceleration of the entire body.

RESULTS

Horizontal and vertical components of the nystagmus slow phase were measured throughout each subject's reaction in the several test trials. Records were divided into two-second intervals; separate averages for the two components were obtained for each interval for each group. Vectorial resolution of these two components then provided a single vector representing the magnitude and direction of the average response for each two-second interval throughout the reaction. Figure 2 presents only the magnitudes of these vectors to facilitate visual comparisons of the response declines. Figures 3A and B show, by vectorial presentation, the magnitude and direction of the nystagmus slow phase throughout the course of the reaction in each group. In addition, the slow phase eye movement displacement throughout the course of each reaction was summed for each subject. Vectorial resolution of these total horizontal and vertical components was then obtained and magnitudes were averaged over subjects, to permit calculation of per cent declines of nystagmus indicated in Table I.

The subjective data are based on the intensity ratings given by subjects. For example, it was assumed that an intensity rating of 4 during the pre-tests and a rating of 2 during the post-tests represented a response decline of 50 per cent. Subjects were questioned after they gave their intensity ratings at the end of the day to check for consistency between verbal estimates and numerical indications of response declines. In Group A, the average decline in subjective response was 75 per cent in the practiced quadrant and 44 per cent in the unpracticed quadrant. In Group B, average decline was 42 per cent in the practiced quadrant and 14 per cent in the unpracticed quadrant.

There was no evidence of a decline in nystagmus produced by the angular accelerations of the SRR, although this was not adequately investigated in this

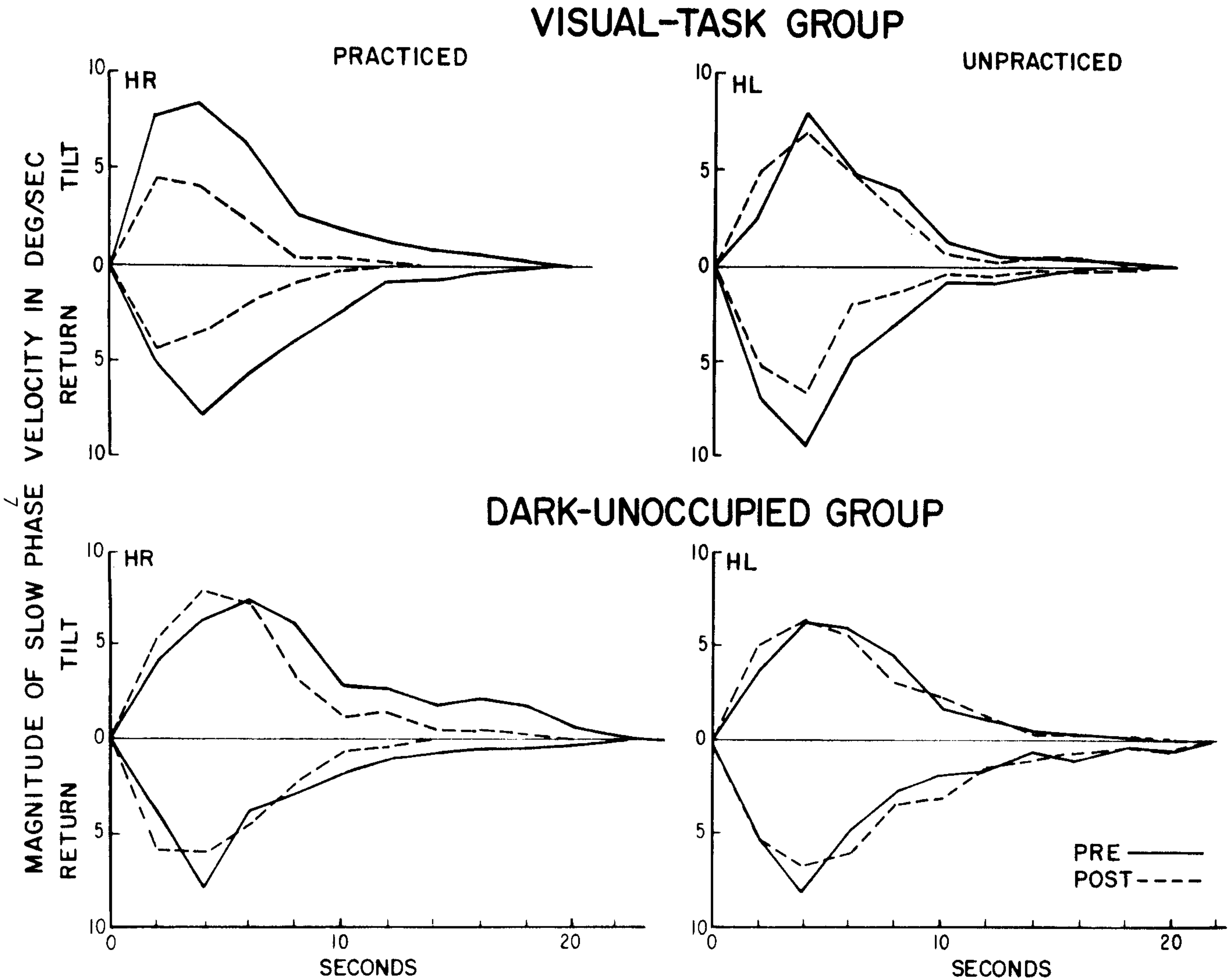

Figure 2

Magnitude of Slow-Phase Velocity of Nystagmus, Obtained by Resolving Records of the Horizontal and Vertical Components of Eye Movements at 2-Second Intervals throughout the Course of the Reactions. Solid and Dashed Lines Indicate Pre- and Post- Tests, Respectively.

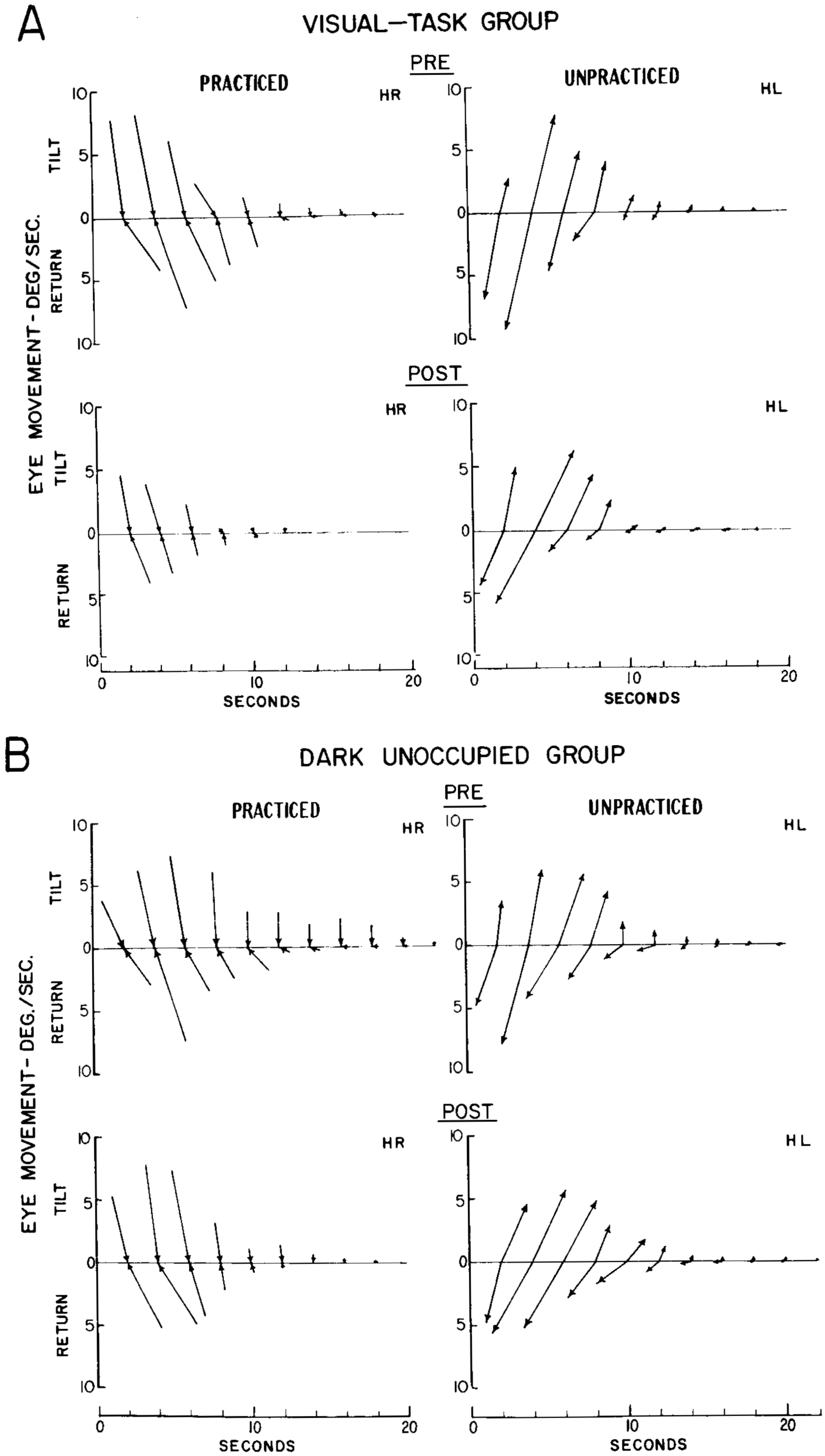

Figure 3

Vectorial Representation of Direction and Magnitude of Nystagmus at Two-Second Intervals throughout the Course of Each Reaction in the Pre- and Post- Tests. Length of the Arrows Indicates Magnitude of the Velocity of the Slow-Phase of Nystagmus; Direction of Arrows Indicates Plane and Direction of the Nystagmus Fast-Phase Relative to the Sagittal Plane of the Skull. An Arrow up and to the Reader's Right Designates Nystagmus with Fast-Phase Directed Diagonally up and to the Right of the Subject's Sagittal Plane.

Table I

Per Cent Change in Nystagmus in Tests before and after Habituation Series.

Minus and Plus Signs Indicate Decrements and Increments, Respectively

	Practiced Quadrant		Unrpacticed Quadrant	
	Tilt	Return	Tilt	Return
Group A	-69	-59	+1	-25
Group B	-31	-18	+18	-2

experiment. Of seven subjects (5 - Group A, and 2 - Group B) who were tested in this manner, all exhibited strong nystagmus during the deceleration which ended the experiment.

Salient features of the results of this experiment were as follows:

1. The rotation tests before and after the habituation series indicated that Group A subjects all demonstrated a clear decline in nystagmus and in subjective effects in the practiced quadrant. In contrast with the previous experiment (19), there were no exceptional subjects who failed to evidence a decline in the practiced quadrant. In the unpracticed quadrant there was little response decline in nystagmus; subjective results evidenced a little more response decline than did nystagmus in this quadrant.

Those subjects whose habituation series was conducted in darkness, Group B, showed little or no decline in nystagmus in the practiced or the unpracticed quadrant. Subjective response declines indicated by this group were less than those indicated by Group A.

2. Group A, the visual-task group, was relatively free of motion sickness symptoms; three of ten subjects reported nausea which disappeared early in the habituation run. None of these subjects vomited. On the other hand, six of twelve subjects in Group B were severely disturbed by motion sickness. Two of these could not complete the experiment, and four subjects vomited several times. When nausea occurred, it usually persisted in Group B throughout the run.

3. In the static tests after the habituation series, Group A reported subjective effects principally in the practiced quadrant. Group B reported little or no effects in the subsequent static tests in either practiced or unpracticed quadrants. These subjective effects in Group A appear indicative of the development of a compensatory reaction evidenced in other studies, but nystagmus did not provide direct evidence of compensatory reactions in the static tests.

The differences in these two groups in regard to response declines are illustrated in Figures 2, 3, and 4. Figure 4 presents nystagmus records from three subjects in each group.

DISCUSSION

Although the average initial nystagmus response was slightly greater in Group B, the pronounced differences between Groups A and B in regard to response declines, nausea, and aftereffects are probably not attributable to initial differences in motion sickness susceptibility between the two groups. Subjects were pilot candidates in the pre-flight training program and were interviewed prior to the experiment in an attempt to match the groups in regard to susceptibility to motion sickness. Moreover, the predominance of subjective effects during the post-

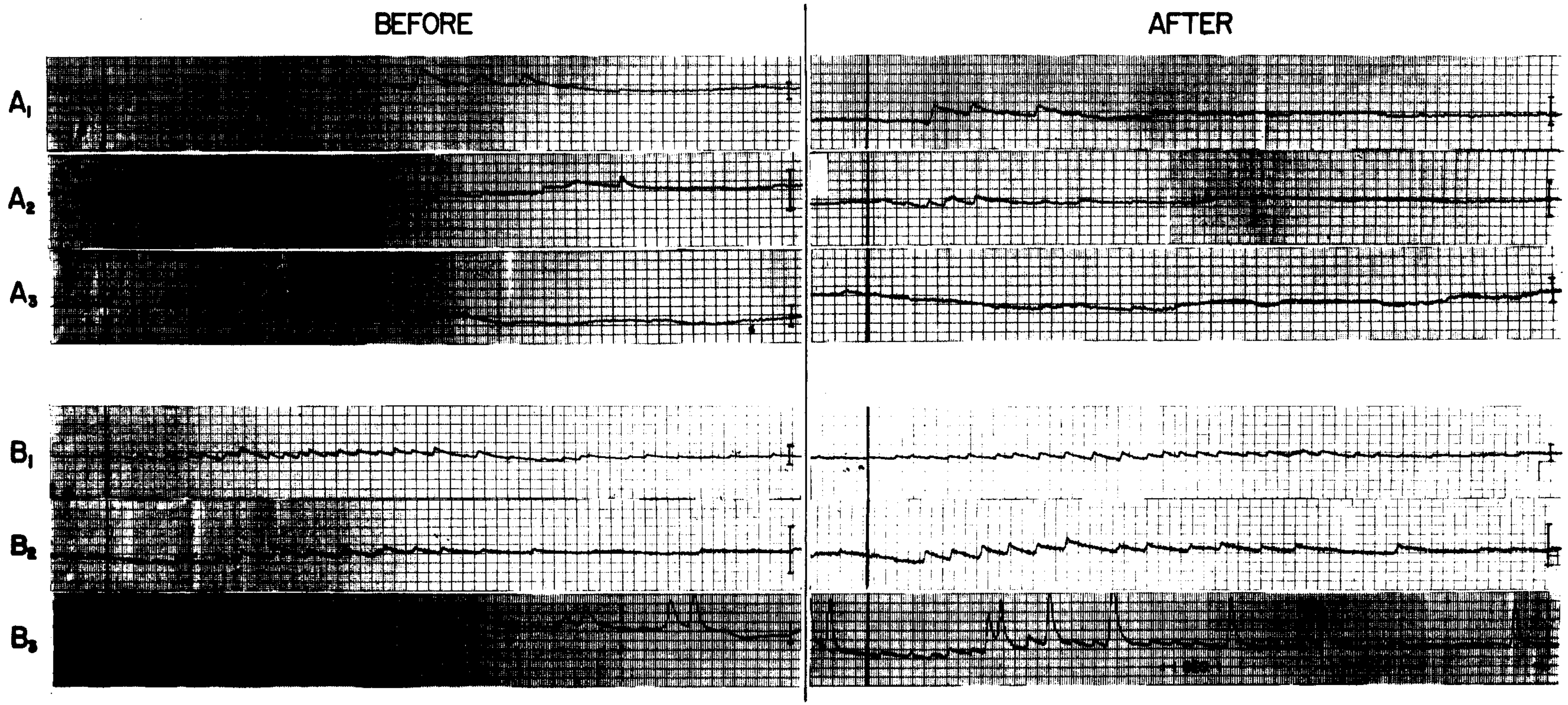

Figure 4

Sample Records from Six Subjects Showing the Vertical-Nystagmus Component Produced by Head-Return from Right Tilt before and after the Habituation Series. Subjects A_1, A_2, and A_3 Were from Group A (Visual-Task Group) and Subjects B_1, B_2, and B_3 Were from Group B. Calibration Markers at Right of Each Record Represent 20 Degrees of Eye Movement. Vertical Lines to Left of Each Record Mark Onset of Head Movement.

habituation static tests in Group A suggests that they were not merely a less susceptible group.

The predominance of sickness in Group B during the habituation program was not anticipated. However, in retrospect, the results in regard to vegetative symptoms agree with spontaneous comments from personnel engaged in Pensacola SRR experiments, namely, that heightened mental activity and interest in a task seem to suppress nausea and malaise. Wendt (32) has made similar comments. In our experiment, a sensory conflict was inevitable in any head movement whether vision was present or not, for the canal influx would be antisynergic with otolith and proprioceptor influx in either case. With vision permitted, otolith, proprioceptor, and visual influx would provide "reafference" [cf. Groen (13) ; v. Holst and Mittelstaedt, (22)] consistent with the voluntary head movements and only canal influx would be antisynergic with other sensory input.

In the present experiment the introduction of a visual task which required voluntary oculomotor control had a definite influence on nystagmus habituation. The average response decline obtained in the present experiment in the visual-task group was slightly greater and was more consistent than the declines obtained in the previous experiment (19) in which subjects experienced similar habituation procedures with vision permitted but without visual tasks being required. These conditions are to be contrasted also with those experiments in which illumination was introduced during repetitive stimulation of restrained animals (8,29). Species differences in reactions to restraint may be one of several subtle factors contributing to variability of results in this line of experimentation [cf. Wendt's comments on "animal hypnosis" of restraint (31,32)], but in any case it is difficult to assess the extent to which voluntary oculomotor control interacts with vestibular effects in animals.

Because subjects in the present experiment were tested in the beginning and at the end of the day, using mental arithmetic to prevent nystagmus loss due to loss of arousal, it is likely that a large portion of the reductions observed is primarily attributable to some process other than the loss of arousal.

In a series of experiments involving repetitive elicitation of the Coriolis vestibular reaction, clear evidence has been obtained for the development of conditioned compensatory reactions (12, 17, 19) which counteract inappropriate patterns of sensory influx. The present experiment suggests that vision is conducive to the development of this compensatory reaction, although it is likely that a pattern of exteroceptive and interoceptive stimuli is involved in releasing the reaction. It is to be noted, however, that, although vision and the voluntary aspect of the movement may facilitate the conditioning process, they are not necessary to the elicitation of the compensatory response once it has been developed (17). Furthermore, the differences between the practiced and unpracticed quadrant in Group B suggest that some factor other than vision, possibly but not necessarily arousal, was influencing results.

The influence of visual oculomotor control on nystagmus habituation may be greater with the unnatural sensory influx of the voluntarily initiated Coriolis vestibular reaction than with other forms of vestibular stimulation. The presence of the information garnered from the voluntary aspect of the movement, the sensory information from the otoliths, proprioceptors, et cetera may be necessary along with visual suppression for the development of the compensatory nystagmus. Some of these elements would not be present in simple vestibular stimulation involving only passive angular acceleration of the subject about a fixed vertical axis. A more recent experiment (16) employing simple passive vestibular stimulation has demonstrated, however, that here also nystagmus habituation in human subjects is influenced by a visual task. These experiments considered together leave little doubt that vision is an important factor in the habituation of vestibular nystagmus in human subjects, and the results are consistent with views expressed previously by Wendt (31,32) and others.

This series of experiments on the SRR appears analogous to studies of adjustment to optical distortion of retinal images (6,23). In these optical experiments, proprioceptive and vestibular influx accompanying movements of the head and body would be normal, but the visual influx would be at variance with influx from these other systems. In these studies, as in those of Graybiel and others (5,11,12,17,19), neurovegetative symptoms and poor coordination occurred initially, but with continued exposure, undesirable and inappropriate reactions diminished. In both situations, return to a natural sensory environment was accompanied by a period of readjustment in which most of the undesirable effects reappeared.

Cohen and Held (6) have demonstrated that active, as opposed to passive, participation of subjects during exposure to bizarre combinations of visual and proprioceptive sensory influx is important in the adjustment they achieve. It seems likely that such a subtle condition, i.e., active as opposed to passive participation, may be important to a series decrement which may occur when visual stimulation suppresses vestibular nystagmus. It has been indicated that nystagmus and disturbance of equilibrium decline markedly in individuals who routinely encounter complex vestibular stimulation by virtue of daily occupation (2,25). Perhaps it is important that these individuals typically initiate the stimulus by their voluntary actions, that they would be endangered by false sensory data, that vision when available would be used actively to suppress nystagmus and apparent motion effects, and that the success or failure of the suppression would usually be comprehended immediately by the participant.

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